INF2178: Experimental Design for Data Science

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Assignment 2

Introduction

The investigation of dementia's impact on brain anatomy is increasingly important given its growing incidence and profound influence on individual health and societal care systems. The analysis centers on data from a longitudinal MRI study that monitors brain changes in patients with and without dementia. During the exploratory data analysis (EDA), I created several plots to visualize the data distribution. The age distribution histogram revealed that participants' ages spanned from 60 to 98 years, with a mean age of 76.41, highlighting the aging demographic under study. The education level varied widely among participants, with the educational years histogram indicating an average of about 14.56 years of education, suggesting a diverse educational background in our sample. The analysis of normalized Whole Brain Volume (nWBV) showed values ranging from 0.646 to 0.837, averaging at 0.731, and this measurement is critical in assessing brain shrinkage, which can be related to cognitive deterioration. Lastly, the distribution of the Clinical Dementia Rating (CDR) predominantly showed scores of 0, indicating an absence of dementia, with a subset showing higher values, signifying various dementia stages.

There were two research questions that were explored in this analysis: (1) Is there a significant difference in brain volume between demented and non-demented groups after accounting for age, gender and education level? and (2) Does the progression of dementia (as indicated by the increase in CDR/time) correlate with a decrease in brain volume?

RQ1: Analyzing Brain Volume Difference by Dementia Status

In the first research question, it was hypothesized that brain volume will significantly differ between demented and non-demented groups, even after accounting for confounding factors such as age, gender, and education level. As seen in Table 1, the mixed-effects ANOVA test results reveals that the difference in normalized Whole Brain Volume (nWBV) between the demented and non-demented groups is not statistically significant, given the p-value (0.081) is above the alpha threshold of 0.05. This suggests that, when considering age, gender, and education level, being demented or non-demented does not lead to a significant difference in brain volume within our study population. However, age and CDR—our proxy for the severity of dementia—are significantly related to brain volume, with both showing negative associations. As age increases, nWBV decreases, which is in line with general expectations regarding brain atrophy with aging. Moreover, higher CDR scores, indicative of greater dementia severity, are also linked with decreased nWBV. This finding aligns with the understanding that dementia is often associated with a reduction in brain volume. In healthcare settings, this knowledge could be important in targeted interventions and could also aid in the refinement of therapeutic strategies. If the decline in brain volume is more closely associated with the progression of dementia rather than its mere presence, treatments could be better tailored to the stages of dementia, potentially offering more personalized and effective care.

Table 1: Mixed-Effect ANOVA of Group, Age, CDR.

Coefficient	Estimate	Std. Error	z-value	P-value	95% CI
Intercept	0.991	0.026	37.554	<0.001	(0.940, 1.043)
Group[T.Demented]	-0.016	0.009	-1.747	0.081	(-0.033, 0.002)
Age	-0.003	0.000	-11.612	<0.001	(-0.004, -0.003)
CDR	-0.013	0.004	-3.277	0.001	(-0.021, -0.005)

Figure 1 further supports these findings. The boxplot (Figure 1a) exhibits median nWBV across non-demented, demented, and 'Converted' groups, aligning with our ANOVA findings where dementia status did not significantly influence brain volume. The scatterplot (Figure 1b) displays a negative correlation between age and nWBV, which statistically supports the conclusion that brain volume decreases as age increases. The scatterplot (Figure 1c) indicates a negligible impact of education level on nWBV, mirroring the ANOVA result that education does not play a significant role in brain volume variance.

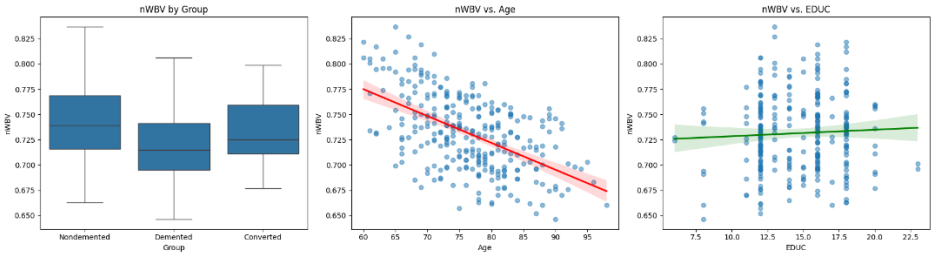

Figure 1. Output plots of (a) nWBV by Group, (b) nWBV vs Age, (c) nWBV vs EDUC

Statistical power analysis furthers our confidence in these findings. To detect an effect size of 0.7 at a power of 0.91 and a significance level of 0.05, approximately 46 participants would be required in each group. This sample size ensures a robust test capability to correctly reject the null hypothesis. The power curve plot, depicted in Figure 2, visually supports this analysis, demonstrating that our sample size is adequate to reveal meaningful differences.

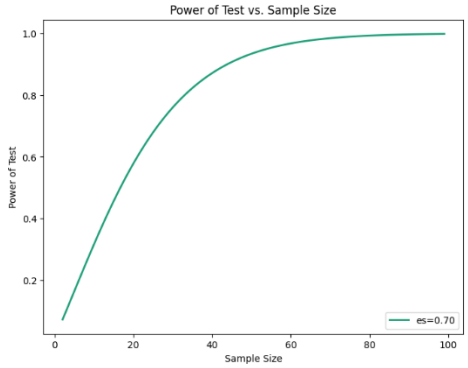

Figure 2. Power plot curve for RQ1

RQ2: Assessing the Relationship Between Dementia

In the second research question, the hypothesis proposed that as dementia progresses, indicated by an increase in Clinical Dementia Rating (CDR), there would be a corresponding decrease in normalized Whole Brain Volume (nWBV). The mixed-effects ANOVA test outcomes, detailed in Table 2, shows a statistically significant negative relationship between CDR scores and nWBV, with a p-value of less than 0.001. This suggests that brain volume diminishes as the severity of dementia increases, which agrees with current understandings of the condition's impact on brain atrophy. In the realm of healthcare, these results have critical implications. The connection between advancing dementia and brain volume reduction could guide the development of prognostic models and inform clinicians about the potential rate of disease progression. Additionally, it could affect decisions regarding when to initiate more aggressive treatments or introduce supportive care strategies.

Table 2. Mixed-Effect ANOVA of CDR on nWBV.

Coefficient	Estimate	Std. Error	z-value	P-value	95% CI
Intercept	0.739	0.003	238.379	<0.001	(0.732, 0.745)
CDR	-0.024	0.004	-5.665	<0.001	(-0.032, -0.015)

Figure 3 further supports these findings. As seen in Figure 3a., the scatterplot demonstrates a clear negative association between CDR scores and nWBV, suggesting that as the severity of dementia increases, brain volume decreases. In Figure 3b., the histogram of residuals offers insight into the model's performance, showing how the differences between the observed and predicted values of nWBV are distributed. The relatively bell-shaped curve suggests that the residuals are normally distributed, which is a good sign of model fit.

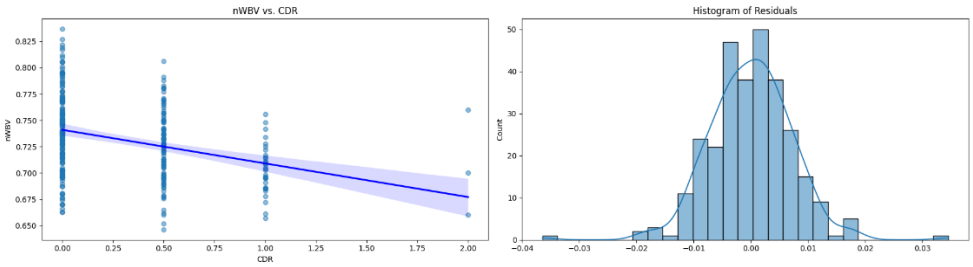

Figure 3. Output plots of (a) nWBV vs CDR scatterplot with regression line (b) Histogram of residuals

The robustness of analysis is further supported by the statistical power analysis. To detect the observed effect size of 0.7 with 91% power and at a significance level of 0.05, a sample size of approximately 46 participants in each group is required. The adequacy of the sample size is visually demonstrated in the power curve plot (Figure 4).

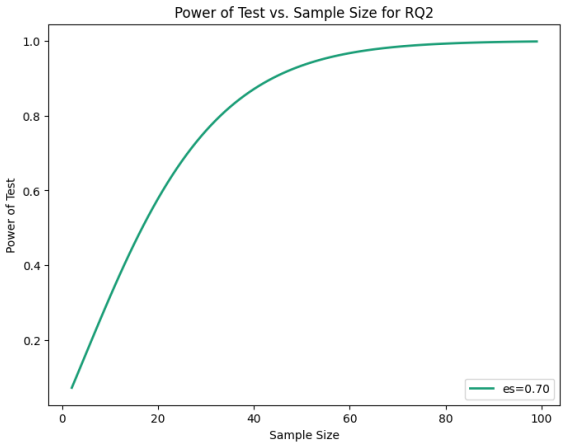

Figure 4. Power plot curve for RQ2

Conclusion

The exploration of brain volume changes in relation to dementia, using longitudinal MRI data, has significant findings. The analysis revealed that dementia status by itself is not a significant factor in brain volume when adjusted for age, gender, and education. However, as dementia severity increases, a corresponding decrease in brain volume is evident. This aligns with the established medical understanding that brain atrophy is closely associated with the progression of dementia-related symptoms. These findings carry important implications for the healthcare industry, especially in terms of developing early diagnostic markers and creating targeted treatment plans. The results indicate the necessity of continuous monitoring of patients with dementia to better understand the rate and nature of brain volume reduction over time. The power analysis provides a solid statistical foundation for these insights, affirming that the study was well-equipped to detect meaningful differences.

The future direction of research in this area could involve examining the potential protective factors that might slow down the rate of brain atrophy or uncovering the specific stages of dementia where intervention may be most beneficial. It may also be good to investigate the effects of various treatment modalities on brain volume to identify the most effective approaches for preserving cognitive function. Further inquiry might focus on the interactions between brain volume changes and other physiological or psychological conditions that often accompany aging. Questions about how lifestyle, diet, or social factors could influence the trajectory of dementia's impact on brain volume also warrant investigation.